



crystal spot detection with infinitesimally small temperature controls

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SUC BACKGROUND OF THE INVENTION

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P There are two distinct ways of using the liquid crystal *analyzing integrated circuits* properties for ~~hot spot detection~~. These are:

P (A) using the light scattering property of the *cholesteric* liquid crystal (see reference 3 & 4), and

P (B) the phase transition property of the liquid crystal (see reference 1 & 2).

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This invention uses the phase transition property of the liquid crystal. Therefore, the discussion shall be limited to the phase ~~transition type of the hot~~ *to the hot* spot detection method.

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There are three kinds of liquid crystals: cholesteric, nematic and smectic. Both the cholesteric and nematic liquid crystal have been used for detecting hot spot (see reference 1 & 2). John Hiatt (see reference 1) reported that with a cross polarized light and a LC-127 cholesteric liquid crystal, he obtained a spatial resolution of ten to twenty microns. Also, the heating was not used, therefore the lowest *detectable* ~~detectable~~ power of the hot spot is in the range of one hundred to two hundred milliwatts. E.M. Fleuren (see reference 2) reported the use of a *N5* ~~N-3~~ nematic liquid crystal phase *to* ~~to~~ detect ~~a~~ hot spots. The particular nematic liquid he used is called N5. He used a P.I.D. control and achieved a constant temperature *of 0.1 degree celsius* ~~of 0.1 degree Centigrade~~ to a specified temperature. He could routinely detect a hot spot of 100 microwatts or more, with the P.I.D. control.

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3 However, by chance, if the liquid crystal's ambient temperature happens to be much less than 0.1 degree *celsius* ~~Centigrade~~ (say a 0.005 degree *celsius* ~~Centigrade~~) below the liquid crystal transition

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temperature, he could detect a lower power hot spot. He managed to detect a hot spot of 3.6 microwatts once.

For a liquid crystal hot spot detection method, the ^{lowest} amount of integrated circuit energy ^{required} ~~requires~~ to induce a liquid crystal phase transition is proportional to the ^{difference} ~~difference~~ between the liquid crystal phase transition temperature and the liquid crystal film's temperature. Before this invention, the temperature control process is to keep the liquid crystal temperature constant. The disadvantage of the constant temperature method ^{was} ~~is~~ that there is no instrument that could control a temperature infinitesimally close to a specified temperature. Also, prior to this invention, the ~~mode~~ ^{mode was} heating is either conductive (see reference 2) or no heating at all (see reference 1). The liquid crystal film's temperature responds slowly to the conductive heat transfer, because a large poor heat conductor exists between the liquid crystal film and the conductive heating system. The same large poor heat conductor induces an uneven temperature profile on the liquid crystal film, thus reducing the ^{sensitivity} ~~sensitivity~~ of the liquid crystal hot spot detection method.

~~The invention use a varying temperature control method. This method enables the liquid crystal film's temperature to be brought to infinitesimally close to the liquid crystal phase transition temperature. Therefore, a ^{below} ~~hot~~ spot with ^{low power hot} ~~one~~ or two~~

~~microwatts could be routinely detected. The sensitivity of this~~

~~invention was helped by using a pulsing input to the hot spot.~~

The difficulty arising from the inability to differentiate between a voltage induced blinking and a hot spot induced

Ins a 5 blinking was solved by ~~the invented varying temperature control~~
as method.

A * Reference 1: John Hiatt, "A Method of Detecting Hot Spots
B on Semiconductors using Liquid Crystals."

19th Annual Proceedings of the IEEE Reliability
Physics Symposium, 1981, Pg. 130-133.
B B 14 B

R * Reference 2: E.M. Fleuren, "A very sensitive, simple analysis
B technique using nematic liquid crystals," 21st
Annual Proceedings of the IEEE Reliability
Physics Symposium, 1983, Pg. 148-149.
B B 14 B

P * Reference 3: J.L. Fergason, "Liquid crystals in
B nondestructive testing," Applied Optics, Vol.7,
No. 9, (sept.) 1968, Pg. 1729-1737.
a *B B 14 B*

P * Reference 4: G.D. Dixon, "Cholesteric liquid crystal in
B nondestructive testing," Material Evaluation,
June 1977, Pg. 51-55.
B B 14 B

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SUMMARY OF THE INVENTION

Ins a 6 ~~Both the collimating of the radiative heating light source and~~
CL the direct overhead heating of the liquid crystal film have
a helped the formation ~~an~~ even temperature profile on the liquid
crystal film. Both the rapid response of the heating filament
temperature and the direct overhead heating have helped to
create a rapid temperature response from the liquid crystal film.
The method of turning on and then turning off the radiative
heating light source method allows the liquid crystal temperature

to rise beyond and then drop below the phase transition

temperatures of the liquid crystal. While the liquid crystal

a temperature ~~rising~~ ^{riser} across a phase transition temperature, there

exists a limited length of time window when the liquid crystal

a temperature is ^{arbitrarily} ~~arbitrary~~ close to the liquid crystal phase

transition temperature. During this limited length of time, an

infinitesimally small heat dissipation from the location in the

a integrated ~~circuit in the~~ ^{circuit to the} liquid crystal film could induce a

localised phase transition in a liquid crystal film. In other

words, the turning on and then turning off the radiative heating

light process enables the temperature of the liquid crystal to be

a brought within an ^{arbitrarily} ~~arbitrary~~ small range of a pre-specified

temperature, for a limited length of time window. For example,

with a carefully selected power level of the radiative heating

light, the liquid crystal temperature is brought to less than

Ans 97 0.001 ~~degree centigrades for~~ more than a few seconds. 16

Ans 98 ^{a7} Essentially, there is no limit ~~how close this invention can~~
as control a temperature to within a specified temperature.

Therefore, in the application of this invention to the liquid

crystal hot spot detection method, the lowest wattage of a

detectable hot spot is not limited by the ability to control the

a ^{temperature of the liquid} ~~temperature the liquid~~ crystal film, but by the width of the 32

temperature bands of the liquid crystal phase transition

temperatures. Prior to this invention, the lowest wattage of a

detectable hot spot was limited by the ability to control the

temperature of liquid crystal film.

a One of the nematic liquid ^{crystals} ~~crystal~~ used for this invention is ⁴ ~~B~~

cyano- 4' hexyl-biphenyl. It is sold by E.M. Chemical under the

B 90

trade name of K-18 nematic liquid crystal. I found it has 4 phase transition temperatures;

transition temperatures, the temperature band width of each phase transition is estimated to be on the order of 0.001 degree

Celsius. All the phase transitions lie within 28.5 and 30.0 degree Celsius. The exact temperature of each phase

transition is not measured, and is not important to this

invention. The K-18 nematic liquid crystal is not the only

chemical that works well for this invention.

The selection of the electrical input power at 1.2 Hz and at 50% duty cycle to the hot spot of the die or wafer produces the

optimal observable and differentiable hot spot blinking effect.

The process of turning the radiative heating light on and off

permits the ambient temperature of the liquid crystal to vary

with the time. Below the phase transition temperature of the

liquid crystal, the size of the hot spot induced blinking

increases as the ambient temperature increases, but the size of

the voltage induced blinking does not respond to ambient

temperature changes. The invented process of turning on and then off the

radiative heating provides a means to differentiate the hot spot

induced blinking from a voltage induced blinking.

BRIEF DESCRIPTION OF THE DRAWING

Figure 1 shows the set-up of the invention.

Figure 2 shows the temperature of the liquid crystal layer and the heating up time

DETAILED DESCRIPTION OF THE INVENTION

Use a signal generator to generate a low frequency signal 1.

(refer to figures 1 and 2) The frequency of signal 1 is 60 hertz

or lower. The preferred signal frequency of signal 1 is around

1.2 Hz. The advantages of 1.2 Hz are (a) 1.2 Hz is slow enough

a for visual observation; (b) ^{close to the human heart} 1.2 Hz is very close to human heart beat rate; therefore, ^{humans} human can easily identify a 1.2 Hz when encountered; and (c) ^β 1.2 Hz is fast enough to form enough number of optical observation phase changes during a short "time window", in which only during the time window the phase ~~the hot spot induced blinking is visible~~ transition is possible.

~~Ans A'10~~ ^{A'10} The signal frequency cannot be higher than 60 Hz, for which human eyes cannot see an optical image change with a frequency higher than 60 Hz. The signal 1 is used to control a switch. The

~~Ans A'11~~ ^{A'11} switch can be either a relay or a solid state switch. The switch 2 can be either an on/off switch or a variable switch. The on/off relay switch is the preferred switch, because the relay switch has no leakage current. The time lengths of the "on" mode and "off" mode of the ^{relay switch 2 is} relay switch are controlled by the wave form, the duty cycle, and the frequency of the signal 1. Any "on" and "off" mode time lengths would enable the invention to function.

The pattern of the preferred "on" and "off" time lengths is: (a) ^{lengths are each equal} the "on" time length and the "off" time length are equal, (b) the "on" time length and the "off" time length each equal to 0.6 seconds. An equal time length produces a maximum optical

~~Ans A'12~~ ^{A'12} resolution for observing the phase transition, at a given signal frequency. The 0.6 seconds time length is chosen because the ^{hot spot induced blinking is slow} phase transition is slow enough for human eyes to observe, yet

^{note} fast enough to generate enough number of observable phase transitions during the short time window. ^{hot spot induced blinking during}

^{A'13} The relay switch 2 is used to chop the D.C. 9th square wave voltage 3 of 1.2 Hz and 50% duty cycle. The square wave voltage 3 is the input to the device under test 4, which is the die 17 or

wafer 40 under test. The whole surface of the device under test has been spread with an even and thin ^{film} layer of nematic liquid crystal. The thickness of the liquid ~~crystal layer~~ ^{crystal film 28} is adjusted to within a specific working range. The thickness adjustment and the thickness determination procedures consist of the following 3 steps: ^B

Step T1: Adjust the light analyser 8 and the light polarizer 16 such that they optically cross polarized.

Step T2: Allow the liquid crystal to cool down below its phase transition temperatures.

^a Step T3: View the liquid ^{crystal film 28 on} ~~crystal thin film on~~ the device under test 4 from the viewing position 12, through the microscope

^a 15. If the liquid crystal thickness is too thin, ^{or there is no liquid} ~~or no liquid~~ crystal at all, the die surface and the liquid crystal would look very dark. Use syringe to spread more nematic ^{liquid crystal onto} ~~liquid onto~~ the die surface, and, use a sharp tipped paper corner to even out the

^a ~~nematic liquid crystal. If the nematic liquid crystal film is transparent but not showing any rainbow color, the nematic liquid~~

^a ~~crystal film is too thick. Use a sharp corner paper to absorb the extra nematic liquid crystal. When the nematic liquid crystal~~

^a ~~thickness reached the optimal working range, the nematic liquid crystal film would look very colorful and transparent. The~~

optimal thickness of the nematics liquid crystal varies from one chemical to another. For the k-18 nematic liquid crystal, the optimal thickness is estimated to be in the range of a tenth of a mil.

A heat absorber 10 is placed on the path of the microscope

illuminating light. The cool light source 20 would have minimum interference on the liquid crystal temperature.

a The heating system consists of two power supplies. The D.C power supply is preferred over A.C. *because D.C. gives a steady* ~~because a D.C. give a steady~~ voltage reading. Each of these power supplies has a variable power control, an on-off switch, a digital voltmeter in series, and one or more light bulbs in parallel. The preferred light bulbs are those with a co-planar filament. A co-planar filament is a requirement for an even heating light. The power supply 5 has a maximum output of around 50 watts; it is for coarse temperature control. The power supply 18 is for fine temperature control; it has a wattage of about a factor of 100 to 1000 lower than power supply 5. The dual switch 23 is capable of turning on or off both power supplies 5 and 18 concurrently. The heating lights 7, 24, 25 and 26 each has a co-planar filament and an objective lens. *to form even and well* ~~The lenses are adjusted to form an even and well~~ collimated light beams. The beams are incident at an angle about 45 degrees from the axis vertical to the surface of the device under test 4. The preferred configuration is the heating lights 7 and 25 facing *each other* ~~each other~~, and the heating lights 24 and 26 are also facing each other. This configuration will cancel the effects of the optical dispersion and the geometrical *attenuation; these effects exist* ~~attenuation, in which effect exists~~ in a single heating light design.

To operate the system, the following steps are taken:

P Step S1: Adjust the curve ^{tracer} 14 to a desired power level. Turn on the on/off switch 27. Turn on the signal generator 13.

P Step S2: Cross polarize the light analyser 8 and the light

polarizer 16.

Step S3: Collimate the heating lights 7, ~~24, 25, and 26~~ ^{24, 25 and 26.}

Step S4: Place the device under test 4 on the microscope stage

29. Use a syringe to spread a layer of nematic liquid crystal on the surface of the device under test 4. Use a cut paper to adjust the thickness as well as to even out the nematic liquid.

crystal film 28 while viewing the nematic liquid crystal layer.

28 through viewing position 12. The nematic liquid crystal layer

28 will be at an optimal thickness when the nematic liquid

crystal film 28 shows a transparent and rainbow color all over the surface of the device under test 4.

Step S4: Adjust the power supply 5 till the solid state temperature sensor 21 reads a temperature of about 0.2 degree

centigrade below the phase transition temperature 32. Allow 10

minutes for the nematic liquid crystal layer 28 and die 17 to reach their equilibrium temperatures. Then select a setting for

the power supply 18. Turn on the heating light switch 22. Time the length of time required for the nematic liquid crystal layer

28 to cross the phase transition temperature 32. The longer the

length of time 35, the more sensitive is this invention in

detecting a low wattage hot spot. I found that if the length of

time 35 was 10 minutes, a 10 microwatts of pointed source hot

spot could be located. If the length of time 35 was 15 minutes,

a 2 microwatts of pointed source hot spot could be located.

However, further increase in the length of time 35 beyond 20

minutes would not further improve the sensitivity of this

invention. At this temperature changing rate, the most limiting

factor is the temperature band widths of the phase transition

temperatures ^{32, 36}~~32, 36~~ and 37. For K-18 nematic liquid crystal, each is estimated to be in the order of ^B0.001 degree ^{kelvins}~~centigrades~~.

Considering ~~the~~ all the heat transfer properties of a typical ^{integrated}~~integrated~~ circuit and the K-18 nematic liquid crystal, the lowest detectable wattage of a hot spot is in the order of ^B1 microwatt.

After the desired power level setting of the ^{power} supply 18 is selected, turn off the heating light switch 22.

Step S5: Turn on the on-off switch 27 to allow the square wave voltage ^B3 to be input to the device under test 4. If the input

voltage ^{was}~~were~~ high enough (about 2 volts for K-18 nematics liquid crystal) ^{the pulsing square wave voltage 3 would}, the ~~pulsing voltage would~~ induce a cyclic disturbance in the nematic liquid crystal ^{film} layer 28. This cyclic

disturbance will show up as a blinking appearance when viewed through the viewing position 12. The blinking is actually a combination of cyclic changes in transparency, brightness and colors. If the input wattage ^{was}~~were~~ high enough to induce a cyclic localized phase transition, the appearance of this cyclic phase transition is very similar to pulsing voltage induced blinking

effect. I shall discuss in step S6 how to differentiate the two

^{kinds of blinkings.}~~effects.~~

If the voltage ^{was}~~were~~ lower than 2 volts, and if the input wattage ^{was}~~were~~ high enough (typically in the order of 500 microwatts) ^B, only the localized cyclic phase transition alone would appear as a blinking spot. If the localized phase

^{transition}~~transition~~ does not show up at 2 volts, additional heating

(described in step S6) ^Bis required.

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Step S6: Turn on the heating light switch 4. Allow the ambient temperature of the nematic liquid crystal ^{film} layer 28, ^{to} continue to rise. As the temperature continues to rise, the blinking spot induced by the localized phase transition will increase in size, or from nothing to an enlarging blinking spot. ^{1a16}

For the voltage induced blinking, the change of temperature change has hardly any effect on the blinking spot size, as long as the liquid crystal temperature is below the phase transition ^{temperature} 32.

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Those hot spots with higher power dissipation are the first to show up as ^{hot spot induced blinkings} ~~blinking spots~~. Those lower power dissipating hot spots are the last to show ~~up~~ the blinking appearance. If the hot spot ^{was} ~~were~~ at 2 microwatts, it would only show up for a few ^{seconds, at just} ~~seconds, at just~~ before the temperature of the nematic liquid crystal ^{film 28} ~~layer~~ rises beyond the phase transition temperature 37.

At any temperature higher than the phase transition temperature 37, both the voltage and hot spot induced blinkings cease to blink; ^{blink; also, the nematic liquid crystal film 28} ~~Also, the nematic liquid crystal layer 28~~ becomes opaque and dark. This particular property is used to determine whether the temperature of the liquid crystal film 28 is below or beyond the phase transition temperature 37.

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Step S6 ^B can be repeated by turning off the light heating switch 22 to allow the ambient temperature of the nematic liquid crystal ^{film} ~~layer~~ 28 to drop below the phase transition temperature 32. Then

^{1a17} repeat ~~the~~ step S6 from the beginning. ^{1a17}

For a typical pointed source hot spot of a typical integrated circuit (for example, a filament type of short in the diode of a input pad of a DL 2416 integrated circuit), this method has ^{been} ~~shown~~ ^B